New Results on Multiplicity, Identified Particles and Spin Measurements in e^+e^- collisions

Vasilii Nomokonov (Helsinki Institute of Physics)
on behalf of the DELPHI collaboration

Abstract

The analyses of recent LEP data provide us with a rich ground for pQCD and LPHD tests. A number of non-trivial effects predicted in the framework of MLLA are experimentally verified. Recent measurements also enrich our knowledge about the hadronization process.

1 Introduction

Recent LEP results on multiparticle production in hadronic jets enable further important tests of QCD. One of the most interesting and intriguing outcomes of the pQCD calculations is the prediction of so-called colour coherence effects [1].

A number of analyses presented here demonstrate that there is an agreement of the data with the QCD MLLA predictions and provide further support for the concept of local parton hadron duality (LPHD) [2].

There are also new results in the physics of large distances, where the processes not calculable within the pQCD provide us with abundant information needed for tuning hadronization model parameters.

2 Testing analytical predictions of Perturbative QCD

Inclusive charged hadron distributions measured by DELPHI at 189 GeV [3] were presented as a function of the variables: rapidity, $\xi_p = ln(1/x_p)$, momentum and transverse momentum. The ξ_p distribution demonstrates the so-called "hump backed" behaviour predicted for partons in the framework of the Modified Leading Logarithmic Approximation (MLLA) [2]. The simultaneous fit to the ξ_p distribution with a Fong-Webber distorted Gaussian [4] at different energies including the present measurement at 189 GeV show very good agreement of the data and the prediction ($\chi^2/dof = 99.6/97$) giving support for the LPHD hypothesis.

MLLA also provides a definite prediction for the energy evolution of the maximum of the ξ distribution, ξ^*. As hadronization and resonance decays are expected to act similarly at different centre-of-mass energies, the energy evolution of ξ^* is expected to be less sensitive to nonperturbative effects. The ξ^* values entering in the analysis were determined by fitting a distorted Gaussian with the parameters given by the Fong-Webber parametrisation. For the 189 GeV data one obtains $\xi^* = 4.157 \pm 0.030$. A fit of the MLLA prediction again demonstrates good agreement while ruling out a phase space expectation and the DLA prediction.

The energy evolution of the momentum distribution is well described by the fragmentation model. An interesting observed feature is the approximate E_{CM} independence of hadron production at very small momenta $p < 1$ GeV. This has been explained in [5],[2] to be due to the coherent emission of long wavelength gluons by the total colour current which is independent of the internal jet structure and is conserved under parton splittings. Therefore, low-energy gluon emission is expected to be almost independent on the number of hard gluons radiated and hence of the centre-of-mass energy. Provided the LPHD hypothesis is correct, the number of produced hadrons at small momenta is approximately constant.

A sample of 2.2 million hadronic Z decays, selected from the data recorded by the Delphi detector at LEP during 1994-1995 was used for a precise measurement of inclusive distributions of π^+, K^+ and p and their anti-particles in gluon and quark jets [6]. As observed for inclusive charged particles, the production spectra of the individual identified particles were found to be softer in gluon jets compared to the quark jets, with a higher multiplicity in gluon jets. A significant enhancement of protons in gluon jets is observed. The ratio of the average multiplicity in g jets with respect to q jets was found for all identified particles to be consistent with the ratio measured for all charged particles. The normalised ratio for protons in Y events was measured to be:

$$R_p = 1.205 \pm 0.041,$$

which differs significantly from unity.

The maxima, ξ^*, of the ξ-distributions for kaons in gluon and quark jets are observed to be different.

A particularly nice illustration of the phenomenon of QCD coherence and a test of LPHD was obtained by DELPHI using symmetric 3-Jet Events [7]. It is known that soft radiation is sensitive to the total colour flow in the underlying hard partonic structure. Let's consider, for example, two extreme two-jet topologies of a $q\bar{q}g$ event. If the gluon is collinear to one of the quarks, the colour flow in the event will be identical to the $q\bar{q}$ case, whereas if the gluon exactly recoils with respect to the two quarks, the colour flow will correspond to that of a gg event. In the latter case the soft radiation at large angle is expected to be increased by the colour factor ratio C_A/C_F as compared to the $q\bar{q}$ case. The evolution between those extreme cases has been calculated as a function of the opening angles between the jets [5]. Thus, the charged hadron multiplicity in a cone perpendicular to the event plane of symmetric three-jet events was determined as a function of an inter-jet angle for the data collected at the Z resonance. A clear dependence of the multiplicity on the opening angle was observed and appears to be in agreement with QCD predictions [8],[5].

An interesting example of the intra-jet QCD coherence is the restriction of forward gluon emission for heavy quarks. A calculation in the framework of MLLA predicts the following angular distribution of gluon emission [1]:

$$\frac{dn}{d\theta^2} \sim \theta^2/(\theta^2 + \theta^2_{min})^2, \quad \theta_{min} \equiv \frac{m_Q}{E}$$

where m_Q and E are a quark mass and energy, respectively. Provided LPHD holds, the effect should be seen, for example, in a comparison of the primary-particle angular distribution for $b\bar{b}$ and $q\bar{q}$ (where q denotes u,d or s quark) Z decays. Delphi has presented preliminary results that show a difference in this behaviour. Hadrons containing the original quark or originating from the decay of such particle are carefully excluded from consideration.

The phenomenon of colour coherence is not only a subject for tests, but also may be used as a tool for reconstruction of the event colour structure on an event-by-event basis. The idea presented in [9] is based on the fact that soft particles do not originate from a particular parton but rather their production depends on the whole colour topology of the event. Therefore, it is possible to define a way to estimate the colour connection strength between the partons by analysing the behaviour of the soft particles. The method can then be used for parton identification. The proposed algorithm is described below: first, fast particles are used to reconstruct cluster directions and then to define a weight w_{ij} that a particle i may be connected to a cluster j with:

$$w_{ij} = \frac{C_i}{k_{ij}^2}$$

where $k_{ij}^2 = 2E_i^2(1 - cos\Theta_{ij})$, with normalisation $\Sigma_j w_{ij} = 1$. Then each particle with $w_{ij} < 0.95$ is assigned to the cluster pair kl for which the sum $w_{ikl} = w_{ik} + w_{il}$ is maximal. Then parton pair connectedness is defined as

$$W_{kl} = C_{kl}\Sigma_i g(E_i)(w_{ik} + w_{il})$$

where i runs through all the particles assigned to the clusters kl.

The method was tested by the Delphi collaboration by using double b-tagged 3-jet Mercedes events collected at the Z pole. The gluon jet is known in these kind of events as one which is not b-tagged. On the other hand, the gluon should have two colour connections and thus the colour connectedness W_{kl} of the $b\bar{b}$ pair must have the smallest value in any given event. Matching the two gives the purity of the method which is found to be above 60% and could be improved by requiring the smallest colour connection coefficient to be below a predetermined threshold value.

The method with various modifications could be used for identifying colour connections in numerous applications (pairing, background rejection).

One of the approaches to study a parton shower cascade is to employ the multiplicity moments technique. The oscillations in the ratio of the cumulant factorial to the factorial charged particle multiplicity moments in Z Decays is known to show a quasi-oscillatory behaviour when plotted versus the order of the moment, as was observed by the SLD collaboration some time ago [10]. This peculiarity is also predicted by the NNLLA of perturbative QCD within the LPHD framework [11].

However, using the jet multiplicity distributions obtained from the Cambridge jet algorithm, in order to vary the dependence on the LPHD hypothesis, the L3 collaboration found [12] that the oscillations appear only for non-perturbative energy scales, namely ≤ 100 MeV. From this conclusion it follows that the observed oscillations are unrelated with the behaviour predicted by the NNLLA perturbative QCD calculations.

Another challenging way to study the cascade is to measure multiplicity fluctuations in rings around the jet axis and in off-axis cones. The DELPHI collaboration performed the measurement [13] and compared them with analytical perturbative QCD calculations for the corresponding multiparton system, using the concept of LPHD. Some qualitative features were confirmed by the data but substantial quantitative deviations are observed.

3 Fragmentation physics

Our knowledge about the hadronization process has been significantly enriched by recent measurements at LEP.

Thus, results on the production of the $\Lambda(1520)$ are presented, as obtained from hadronic Z decays recorded by DELPHI [14]. The $\Lambda(1520)$ scaled momentum (x_p) spectrum is determined. The relative importance of $\Lambda(1520)$ production increases with x_p similarly to that of orbitally excited mesons. It is shown that the $\Lambda(1520)$ primarily originates from fragmentation and not from heavy particle (b, c) decays. The large $\Lambda(1520)$ production rate $N_{\Lambda(1520)}/N_Z = 0.030 \pm 0.004 \pm 0.005$ suggest that many stable baryons descend from orbitally excited baryonic states.

The OPAL collaboration measured the helicity density matrix elements ρ_{00} of $\rho(770)^{\pm}$ and $\omega(782)$ mesons produced in Z^0 decays [15]. Over the measured meson energy range, the values are compatible with 1/3, corresponding to a statistical mix of helicity -1, 0 and 1 states.

For the highest accessible scaled energy range $0.3 < x_E < 0.6$, the measured ρ_{00} values of the $\rho^{\pm}$ and the ω are 0.373 ± 0.052 and 0.142 ± 0.114, respectively.

The ALEPH collaboration performed an extensive study of the production rates and the inclusive cross sections of the isovector meson π^0, the isoscalar mesons η and $\eta'(958)$, the strange meson K^0_S and the Λ baryon. This was done as function of scaled energy (momentum) in hadronic events, two-jet events and each jet of three-jet events from hadronic Z decays and compared the results to Monte Carlo models [16]. The JETSET modelling of the gluon fragmentation into isoscalar mesons is found to be in agreement with the experimental results for the measured region. HERWIG fails to describe the K^0_S spectra in gluon-enriched jets and the Λ spectra in quark jets.

An interesting idea which helped to understand the production rates of light-flavour hadrons was proposed by P.Chliapnikov [17]: the difference between the production rates of hadrons composed of the same quarks and belonging to the different SU(3) multiplets but the same SU(6) multiplet is essentially determined by the hyperfine mass splitting. This trend shows up when the direct production rates are plotted versus the sum of the constituent quark masses $\Sigma_i(m_q)_i$. In this case the vector-to-pseudoscalar and decuplet-to-octet suppressions are found to be the same. In the proposed scenario the strangeness suppression factor, $\lambda = 0.295 \pm 0.006$, is the same for mesons and baryons and related to the difference in the constituent quark masses, $\lambda = e^{-(m_s - \hat{m})/T}$, where $\hat{m} = m_u = m_d$, and the temperature $T = 142.4 \pm 1.8$ MeV/c^2.

References

[1] For a recent review see Khoze V A, Ochs W 1997, *Int. J. of Mod. Phys.* A **12** N17

[2] Azimov Ya et al. 1985, *Z.Phys.* C **27** 65; Azimov Ya et al. 1986, *Z.Phys.* C **31** 213

[3] DELPHI collaboration, EPS HEP99, contributed paper #1_225

[4] Fong C P and Webber B R 1989, *Phys. Lett.* B **229** 289

[5] Khoze V, Lupia S and Ochs W 1997, *Phys. Lett.* B **394** 179

[6] DELPHI collaboration, EPS HEP99, contributed paper #3_146

[7] DELPHI collaboration, EPS HEP99, contributed paper #1_145

[8] Azimov Ya et al. 1985 *Phys. Lett.* B **165** 147

[9] Orava R et al. 1998, *Eur. Phys. J.* C **5** 471

[10] Abe K et al. 1996, *Phys. Lett.* B **371** 149

[11] Dremin I M and Nechitailo V A 1993, *JETP Lett.* **58** 881

[12] L3 collaboration, EPS HEP99, contributed paper #1_276

[13] DELPHI collaboration, EPS HEP99, contributed paper #1_222

[14] DELPHI collaboration, EPS HEP99, contributed paper #3_147

[15] OPAL collaboration, EPS HEP99, contributed paper #3_63

[16] ALEPHI collaboration, EPS HEP99, contributed paper #1_394

[17] DELPHI collaboration, EPS HEP99, contributed paper #3_561